AN IMPROVED FIREFLY ALGORITHM FOR OPTIMAL MICROGRID OPERATION WITH RENEWABLE ENERGY

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A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

JULY 2017

ACKNOWLEDGEMENT

In the name of Allah, The Most Gracious and The Most Merciful

First of all, I wish to praise God, the Almighty God and the benevolent for given me the strength and time to complete this task. I would like to express my sincere appreciation to my supervisor; Dr. Mohd Noor Bin Abdullah for his thoughtful insights, helpful suggestions and continuous support in the form of knowledge, enthusiasm and guidance throughout this master project.

Special thanks to my family, especially my wife (Norhasikin Binti Ismail) and my parents for their constant encouragement and always praying for my success and also very supportive throughout my studies. A million thanks to my MSc/PhD colleagues; Mr. Azmi Sidek and Mr. Ariffuddin Joret, thank you so much for your ideas, motivations, involvement and support during our MSc journey. A special thanks to all lecturers in the Department of Electrical Power Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia.

Finally, I would like to express my gratitude and appreciation to Universiti Tun Hussein Onn Malaysia for the financial support and facilities. I really appreciate having this opportunity to finish this project. This task has taught a lot of lesson and knowledge that would be valuable to me in the future. THANK YOU.

ABSTRACT

Lately, an electrical network in microgrid system becomes very important to rural or remote areas without connection from primary power grid system. Higher cost of fuels, logistic, spare parts and maintenance affect the cost for operation microgrid generation to supply electrical power for remote areas and rural community. This project proposes an Improved Firefly Algorithm (IFA), which is a improvement of classical Firefly Algorithm (FA) technique using characteristic approach of Lévy flights to solve the optimal microgrid operation. The IFA has been used for optimizing the cost of power generation in microgrid system where daily power balance constraints and generation limits are considered. The microgrid system for this case study considered both of renewable energy plant and conventional generator units. There are two test systems that have been considered as case study. The first test system is a simple microgrid system which consists of three generators. The second test system consists of seven generating units including two wind turbines, three fuel-cell plants and two diesel generators. The IFA method has been implemented using MATLAB software. The results obtained by IFA was compared to FA and other algorithms based on optimal cost, convergence characteristics and robustness to validate the effectiveness of the IFA. It shows that the IFA obtained better results in terms of operating costs compared to FA, Differential Evolution (DE), Particle Swarm Optimization (PSO) and Cuckoo Search Algorithm (CSA).

ABSTRAK

Akhir-akhir ini, rangkaian elektrik dalam sistem mikrogrid menjadi sangat penting untuk kawasan luar bandar dan pedalaman yang tidak mempunyai sambungan utama sistem kuasa grid. Kesan kenaikan kos bahan api, logistik, alat ganti dan penyelenggaraan memberi kesan kepada kos yang lebih tinggi untuk operasi penjanaan kuasa mikrogrid bagi membekalkan tenaga elektrik kepada masyarakat luar bandar dan pendalaman. Projek ini, telah mencadangkan *Improved Firefly Algorithm* (IFA) yang ditambahbaik, yang mana merupakan penambahbaikan teknik *Firefly Algorithm* (FA) klasik dengan menggunakan pendekatan ciri-ciri penerbangan *Lévy* untuk menyelesaikan masalah pengoptimuman mikrogrid. IFA telah digunakan untuk mengoptimumkan kos penjanaan kuasa dalam sistem mikrogrid di mana kekangan keseimbangan kuasa harian dan had penjanaan kuasa dipertimbangkan. Sistem mikrogrid untuk kajian kes ini adalah terdiri daripada gabungan loji tenaga boleh diperbaharui dan unit-unit penjanakuasa konvensional. Terdapat dua sistem ujian yang telah dipertimbangkan sebagai kajian kes. Sistem ujian pertama adalah sistem mikrogrid mudah yang terdiri daripada tiga penjanakuasa. Sistem ujian kedua terdiri daripada tujuh unit penjanakuasa termasuk dua turbin angin, tiga loji sel bahan bakar dan dua penjana diesel. Kaedah IFA telah dilaksanakan menggunakan perisian *MATLAB*. Keputusan yang diperolehi oleh IFA telah dibandingkan dengan FA dan algoritma lain berdasarkan kos optimum, ciri-ciri penumpuan dan kekukuhan untuk mengesahkan keberkesanan IFA. Hasil kajian menunjukkan bahawa IFA mendapat keputusan yang lebih baik dari segi kos operasi berbanding *Firefly Algorithm* (FA), *Differential Evolution* (DE), *Particle Swarm Optimization* (PSO) dan *Cuckoo Search Algorithm* (CSA).

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LIST OF SYMBOLS AND ABBREVIATIONS

CSA	-	Cuckoo Search Algorithm
DE	-	Differential Evolution
DG	-	Distributed generation
ED	-	Economic Dispatch
Eff.	-	Efficiency
FA	-	Firefly Algorithm
IFA	-	Improved Firefly Algorithm
i^{th}	-	No. of iterations
kW	-	KiloWatt
PSO	-	Particle Swarm Optimization
P_{min}	-	Minimum power output of generator
P_{max}	-	Maximum power output of generator
$a_i, b_i, c_i,$	-	The cost coefficient of the i^{th} generator unit
$C_i(P_i)$	-	The total fuel cost
h	-	Hour
n	-	No. of population Fireflies Algorithm
P_D	-	Power demand
P_i	-	The real power output of generator i^{th}
v	-	Wind Speed
α	-	Randomization parameter of FA
β	-	Attractiveness parameter of FA
γ	-	The absorption coefficient
$	-	Dollar

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Recently, microgrids play a significant role to sustain generating and distribution of power energy system in modern electric networks. Microgrids are small scale network that supply power from renewable or conventional generating plant to small community such as rural area or islands with limited or no connection to main grid power [1]. A microgrid can operate as an independent system [2] and can be connected or disconnected from primary grid which is operated autonomously when the main grid is down. Besides strengthening power efficiency, stability and reliability for operation, the most challenging issue of microgrid is the economical operation. Since then, investigations on methods optimizing microgrid operation become a significant study among many researchers.

Thereby many researches have been used and proposed several optimization methods to reduce the operation cost of power generation in microgrid. Basu et al. [3] applied differential evolution (DE) method to reduce the emission and fuel cost in microgrids and M. Modiri et al. [4] have used an iteration based optimization method to minimize total cost generation and find out the schedules of generating units in power system. In some cases, as the microgrids consist of various types of generation units, optimal cost has become the most important target for overall operation [5].

The finest solution to ensure the microgrids operate under optimal cost is by implementing optimization technique. Therefore, an Improved Firefly Algorithm (IFA) is propose in this project for determining the optimal power output for each generator in order to obtain the lower cost operation for microgrids. The FA algorithm was pioneer developed by Yang in 2008 [6], which is inspired by the behaviour of the fireflies. Firefly algorithm has been applied to solve optimization problems since early 2009. Many problems from various areas especially in engineering fields were successfully solved using FA. In recent years, some improvement; modification or even hybridization of FA started to be explored by many researchers with the aim to overcome computational constrain to become more flexible and efficient for future application [7].

In this research project, IFA will be used to solve the generation scheduling in microgrid system consisting of combination of conventional and renewable energy generating such as diesel fuel, wind turbine and fuel cell plant. However, this chapter will discuss the overview of the study beginning with research background followed by problem statement. Research objectives, research contributions, research scopes, research methodology and research significance are presented in the following section.

1.2 Problem Statement

The main problem of the research is determining optimal cost microgrid operation through generation cost minimization while satisfying the constraint and load demand. The challenge is greater when the generation of microgrid consists of various sources with different costs for each source whether its renewable or conventional resources. Although the operating cost is most significant but the performance of microgrid also needs to be optimum. Therefore an improved firefly algorithm will be applied to minimize the generation cost.

Despite that, several researchers have used FA in optimization problems but classical FA still have weaknesses in terms of adjusting parameter and inconsistency ability. Therefore, the FA can be improved with some improvement or modification on the algorithm in order to obtain the best optimization solution compared to FA in future.

1.3 Project Objectives

The objectives of this project are as follow:

(a) To propose an Improved Firefly Algorithm (IFA) for solving optimal generation power scheduling in microgrid system.
(b) To investigate the performance of an Improved Firefly Algorithm (IFA) for minimizing operation cost in microgrid within 24 hours.
(c) To compare the results of an Improved Firefly Algorithm (IFA) with FA and other well-known algorithms in microgrid operation.

1.4 Project Scopes

In this study, there are three (3) scopes. The research has been conducted with the following limits:

(a) This study has focused on reducing cost operation in microgrid using an Improved Firefly Algorithm (IFA) technique.
(b) The software tools applied for IFA technique is MATLAB version R2013b.
(c) Dispatch duration for minimizing cost operation is within 24 hours.
(d) The microgrid system consists of renewable energy such as two unit of wind turbine plants, three units of fuel-cell plants and conventional such as two units of diesel fuel generators for this case study.
(e) Investigate the performance of IFA in terms of generated power output, cost minimization, simulation time, convergence characteristics and robustness.
(f) Comparison between the IFA and other algorithms.

1.5 Project Methodology

A flowchart of the general overview of the project is presented in Figure 1.1 as follows for guideline during the project execution.

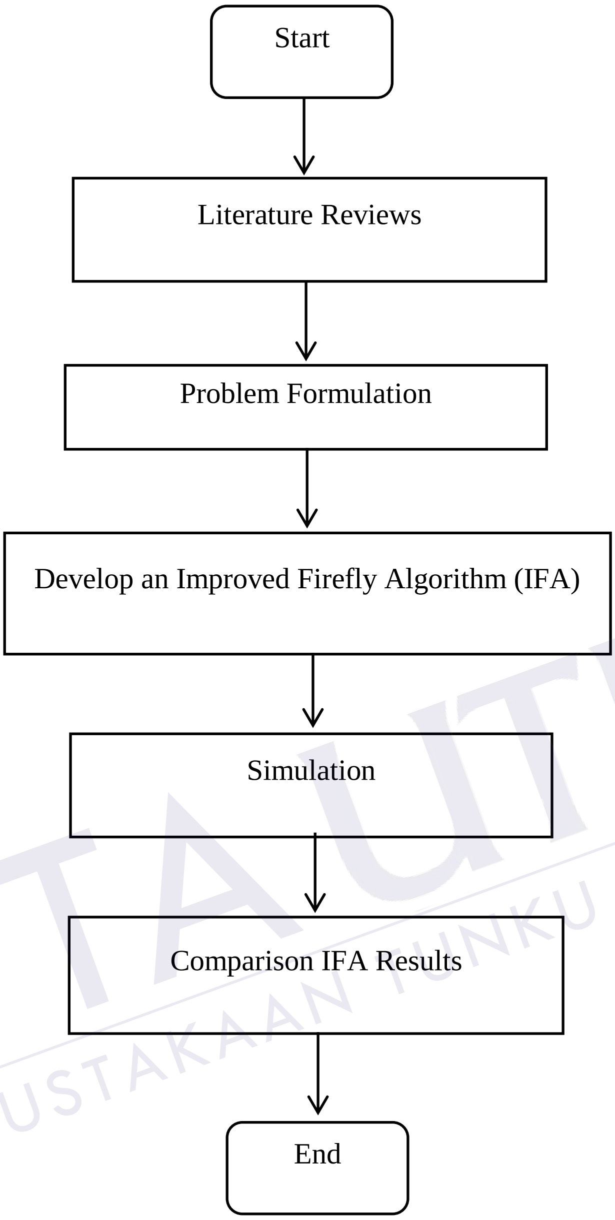

Figure 1.1: A flowchart of the general methodology of the project

In order to achieve the objectives of this study, the following methodology is used as guideline during the study.

(a) In literature reviews: Explanation of related case studies from previous research or technical paper, research gap and objective determination.

(b) Problem formulation: Provide the solving formula or idea of overcoming the problem such as in this case, the problem is to minimize the cost generation of microgrid within 24 hours.

(c) Develop Firefly Algorithm in MATLAB: For initial stage to create programming FA in MATLAB command. Then impose a few modifications or improved original FA coding during research study. In this developing programming codes for solving optimization problem - using IFA. After that identify and compile the objective/fitness function, parameter and boundary setting from formulation problem into IFA programming. At the end of this section, after IFA has finished simulating, results of optimal power generators and minimum cost operation of microgrid as our main goal of research study will be obtained.

(d) Perform data test using IFA: The test depends on the valid resource data from previous recommended research paper with consent of author and supervisor. The test system and parameter applied depend on requirement. Detail explanation regarding test system will be covered in methodology section (Chapter 3).

(e) Conduct Comparison between IFA with other algorithms: Compare results (optimum power and cost operation) between IFA to other algorithms (DE/PSO/CSA) to investigate optimization level to obtain best minimal operation cost in microgrid.

(f) Analyse the performance of IFA: Carry out sensitivity analysis to investigate IFA such as convergence performance.

1.6 Significance of the Project

In the previous research, it was found that the optimal operation microgrid is the most significant issue in the modern electrical system. In microgrid, besides focusing on economical operation, it also serves to fulfil the optimum power demand. These works have opened up the scope of IFA as one of efficient optimizing methods to reduce cost operation microgrid. Specifically, the significance of this study could be listed as follows:

(a) Enhance insight regarding the knowledge of determining the significant small modification or hybridization of FA techniques in the fireflies for example insect behaviour imposed with Gaussian, Lévy flights or Chaos distribution method for problem optimization solution.

(b) Since IFA technique has improved compared to FA, the algorithm improvement will provide more precise efficient and flexible method, beneficial in many fields. This contributes to solving optimal generation power scheduling with minimum operation cost in microgrid for real-world problems.

1.7 Report Organization

This report orderly consists of 5 chapters. The content of each chapter is explained briefly as follows:

Chapter 2: includes discussion and summarization of previous researches and theories of the relevant research works conducted by other researchers in similar field through literature review.

Chapter 3: presents the methodology being used to construct this project. The details of method process are discussed in this chapter.

Chapter 4: shows the results obtained of IFA and the results are being analysed completely. Then, discussion on results obtained are compared to FA and other algorithms in the case study.

Chapter 5: presents the conclusion, recommendations, and future work on the case study towards achievement of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, a literature review of microgrid operation and optimizing techniques that have been used to solve the microgrid optimization problem will be discussed. Recently, the operation cost of microgrid region on the generation and distribution of power supply to the local community has become a critical issue for many years. Therefore economic dispatch (ED) problem is the root of optimization problem. Thereby, the economic dispatch is described in this chapter to understand the problem. A review of economic dispatch in microgrid from a previous study is also discussed in this chapter with various applications for solving problems. The review on economic dispatch will be described in sub-chapter 2.2. The theory of microgrid system is explained in sub-chapter 2.3. Sub-chapter 2.4 and 2.5 described the review by various researchers related to renewable energy resources and optimization methods applied in microgrid. The general theory of Firefly Algorithm is explained in sub-chapter 2.6, with its application in several fields. The review of improvement or upgrading FA in previous research for solving optimization problems in several fields become new challenges for researcher to find the best current solution and this will be described in sub-chapter 2.7. Lastly, the discussion on summary of overall literature review of sub- topic related with research study in order to achieve the objective of this project will be explained in sub-chapter 2.8.

2.2 Economic Dispatch

The economic dispatch (ED) is a short-term determination of optimal power output at lowest probable cost while fulfilling the operational constraints. The economic dispatch of power system can be categorized into static and dynamic dispatches [8]. The dynamic economic dispatch is more suited with an actual operation system, which is for coordinates between the different distribution generations (DGs) over several periods other than considering the lowest cost in scheduling cycle. Meanwhile the static economic dispatch is based on the operating conditions of system over independent period to determine their priority and operation mode of power generating equipment. Therefore many researches on dynamic economic dispatch for optimal generation scheduling in microgrid is very vital. The research in [9] introduced model CHP microgrid by proposing a Monte Carlo simulation based on Leapfrog Firefly Algorithm (LFA) to solve optimization problem for dynamic economic dispatch. The CHP model consists of wind turbines (WT), photovoltaic cells (PV), micro turbines (MT), storage batteries (SB), gas-fired boilers, heat load and electric load. Final finding of the research concludes that dispatch period is rather long since the characteristic of microgrid shows that the outputs of microsources change very fast making the model built is not taken into account.

Han et al. [10], presented a study on the factors that affect the feasibility and optimality solution for dynamic economic dispatch (DED). It proposes two methods for solving the optimization problems; which is to provide feasible and optimal solution for power generation. The 5-unit and 10-unit system are selected for test with various solution methods such as heuristic, unconstrained, optimal and look ahead. Thus, the results above on attempted methods succeeded in providing two solution techniques to obtain the best solving for optimization for DED problems. These two new techniques provide; firstly, to find a feasible solution for all load profiles and secondly, an efficient technique for finding the optimal solution for cost operation minimization.

A new algorithm is presented by Modiri-delshad et al. [11] to resolve the economic dispatch as an optimization problem in power systems. They developed a simple Iterated-based algorithm (IBA) for solving the total cost generation minimization in their proposed model, which is a stand-alone microgrid, consisting of three distributed energy sources. The simulation results are compared to the results achieved by CPLEX solver. The results showed that in order to reduce the objective function of economic dispatch problem in spite of of the guess, the algorithm can find the best schedule of generation.

A Harmony Search Algorithm (HSA) is employed to solve the dynamic economic dispatch problem for microgrid presented by Jha et al. [12]. The research presented the power generation cost minimization of a microgrid comprising of WT, PV, DE and FC. Considering dynamic grid cost, the dynamic economic dispatch of microgrid also establishes the coordination between different distributed generations over many periods. Moreover, in order to maintain the reliability of the microgrid system, various scheduling strategies are employed.

A Weighted SumTime-Varying Differential Evolution (TVDE) is used to solve the dynamic economic emission dispatch with loss and heat optimization for microgrid [13]. The research study highlighted the power generation cost minimization and emission reduction of a microgrid. The microgrid consists of DE generator, WT, MT, SB, PV and FC. The technique proposed is to address economic emission dispatch with loss and heat optimization problem by creating sets of Pareto-optimal results. The results obtained show that TVDE gives better results for simultaneous optimization of four objectives like cost, emission, heat and loss in a microgrid.

2.3 Microgrid

In general, a microgrid refers to a small-scale version of the electricity or low voltage distribution of centralized system that consists of distributed energy resources (DERs). Other than that, microgrid sometimes can operate in either islanded; when a main utility grid faces serious problems, the power is constantly supplied to customers in the islanding operation [14] or grid-connected mode. There are two features of a microgrid; the integration of renewable sources and the use of combined heat and power (CHP) generators. These combinations increase the overall efficiency and contribute a great advantage to electricity system in microgrids. Hayden et al. [15] elaborated the microgrids consisting of several types depending on environment scale requirement such as community utility microgrid, commercial and industrial microgrids, campus or institutional microgrids, military base microgrids and finally remote “off-grid” microgrids.

The advantages of microgrid to utilities and the community are lower greenhouse gas (GHG) emissions, increases efficiency to enable renewable energy and decreases carbon footprint by reducing power losses due to generating electricity through long distance main-grid transmission or distribution network [16]. The primary objective of microgrids is to ensure affordable energy reliability, security network and power stable delivery to utility consumers.

Table 2.1: Comparison of traditional power grids and microgrids.

Performance Measure	Traditional Power Grids	Microgrids
Cost	At most locations in the U.S., power delivery costs between 6 and 15 cents/kW.	Microgrids are capable of lowering fuel costs to under 10 cents/kWh
Fuel Efficiency	Fuel efficiency is $30% to $50% depending on the type of participating power plants.	With combined heat and power (CHP), fuel efficiency can increase to 70%–90%.
Reliability	The average reliability of a power grid is 99.97%	Microgrids can achieve higher reliability if they have traditional power system as backup.
Emissions	Emission issues of traditional power plants are a major concern. By combining traditional power generation with natural gas, emission issues can be alleviated.	Emission issues are significantly resolved by using fuel cells, power PV, wind and others, in microgrids.
Security	Damage to major infrastructure induces a significant impact on a large number of customers	Only local customers are affected by the damage in Microgrids.
Construction Constraints	Difficult to build new lines and substations.	Microgrids can be used to release conventional construction constraints in a traditional power system.

Since microgrid can function in various categories, it is more significant compared to traditional power grid. In addition, comparison between microgrid and traditional power grid was conducted in terms of cost, fuel efficiency, reliability, emissions, security, and construction constraints presented by Lu et al. [17] as summarized as in Table 2.1.

Based on the comparison, the microgrids provide better value proposition than power-grid. To further enhance the reliability and resilience of power generation in microgrids, proposed multiple microgrids can be connected to form an interconnected network as one of the best solutions if a large load demand can be separated and supplied by multiple microgrids.

Furthermore, when microgrids operate in grid-connected mode, it can also generate income for essential consumers and business by reselling the microgrid power to the grid or utility[17]. The ancillary services sold could include demand response, real-time price response, day-ahead price response, voltage support, capacity support and spinning reserve[15].

However, there are disadvantages of microgrids which is difficulty of setting parameter (voltage, frequency, power quality) because the parameter must be controlled to acceptable standards whilst the power balance is maintained in microgrid operation [15]. Besides that, microgrid requires more space and maintenance due to the battery banks [18]. Moreover, the difficulty of resynchronization with the utility grid, protection problems, and issue regarding obstacles to standby charges/net metering and inconsistency application are due to interconnection standards IEEE P1547 [19].

2.4 Review of Optimization Methods of Generation Scheduling for Microgrids Operation.

As an important entity to implement renewable generation technologies combined with conventional fossil fuel based generators, microgrid is expected to operate optimally to minimize the use of fossil fuel. Therefore, the optimal generation scheduling under a swarm intelligence optimization is the best solution method for operation problem in microgrids. Therefore, the swarm intelligence optimization methods have been widely used for solving optimization problems including generation scheduling in microgrids. The goal of the optimization problem is to find the set of variables that results in the optimal value of the objective function to meet the constraint requirement.

REFERENCES

[1] M. Modiri-Delsha, N. A. Rahim, S. S. Taheri, and S. J. Seyed-Shenava, "Optimal Generation Scheduling in Microgrids by Cuckoo Search Algorithm," in *2014 3rd IET Int. Conf. Clean Energy Technol.* 2014, no. 2, p. 10 (5 .)-10 (5 .), 2014.

[2] N. Cai, N. T. T. Nga, and J. Mitra, "Economic dispatch in microgrids using multi-agent system," *2012 North Am. Power Symp. NAPS 2012*, 2012.

[3] A. K. Basu, A. Bhattacharya, and S. Chowdhury, "Planned Scheduling for Economic Power Sharing in a CHP-Based Micro-Grid," *Power Systems, IEEE Transactions on*, vol. 27, no. 1, pp. 30–38, 2012.

[4] S. H. Aghay, E. Taslimi, J. Selvaraj, and N. A. Rahim, "An Iterated-Based Optimization Method for Economic Dispatch in Power System," in *2013 IEEE Conference on Clean Energy and Technology (CEAT)*, 2013, pp. 88–92, 2013.

[5] L. Toma, I. Tristiu, and C. Bulac, "Optimal generation scheduling strategy in a microgrid," *2012 3rd IEEE PES Innovative Smart Grid Technologies*, 2012, no. 4, pp. 491–496, 2012.

[6] I. Fister, X. S. Yang, and J. Brest, "A comprehensive review of firefly algorithms," *Swarm Evol. Comput.*, vol. 13, pp. 34–46, 2013.

[7] N. Ali, M. A. Othman, M. N. Husain, and M. H. Misran, "A review of firefly algorithm," *ARPN Journal of Engineering and Applied Sciences*, vol. 9, no. 10, pp. 1732–1736, 2014.

[8] H. Wu, X. Liu, and M. Ding, "Electrical Power and Energy Systems Dynamic economic dispatch of a microgrid : Mathematical models and solution algorithm," *Int. J. Electr. Power Energy Syst.*, vol. 63, pp. 336–346, 2014.

[9] X. Lin, P. Li, J. Ma, Y. Tian, and D. Su, "Dynamic optimal dispatch of combined heating and power microgrid based on leapfrog firefly algorithm," *ICNSC 2015 - 2015 IEEE 12th Int. Conf. Networking, Sens. Control*, no. 50977029, pp. 416–420, 2015.

[10] X. S. Han, H. B. Gooi, and D. S. Kirschen, "Dynamic Economic Dispatch : Feasible and Optimal Solutions," *IEEE Trans. Power Syst.*, vol. 16, no. 1, pp.

22–28, 2001.

[11] M. Modiri-delshad, S. Koohi-kamali, E. Taslimi, and S. H. Aghay, "Economic Dispatch in a Microgrid through an Iterated- Based Algorithm," in *2013 IEEE Conference on Clean Energy and Technology,* 2013, pp. 82–87, 2013.

[12] R. Jha *et al.*, "Dynamic Economic Dispatch of Micro-grid using Harmony Search Algorithm," *Elect. Power and Energy Syst.*, pp. 1–6, 2015.

[13] M. Grid, A. Pathak, and M. Pandit, "Dynamic Economic Emission Dispatch with Loss & Heat Optimization for a Micro-Grid," in 2014 *PIICON*, 2014, pp. 326–336, 2014.

[14] W. Shi, X. Xie, C. Chu, and R. Gadh, "Distributed Optimal Energy Management in Microgrid," *IEEE Trans. Smart Grid*, vol. 6, no. 3, pp. 1–10, 2015.

[15] E. Hayden and C. Ceh, "INTRODUCTION TO MICROGRIDS," pp. 1–13, 2012.

[16] N. Bartek and G. Montes, "Microgrids, macro benefits:" pp. 1-8, 2014.

[17] F. García, "Optimal Economic Dispatch for Renewable Energy Microgrids with Hybrid Storage using Model Predictive Control," *IEEE Conf.*, pp. 7932–7937, 2013.

[18] F. Zhang and C. Meng, "Advantages and Challenges of DC Microgrid for Commercial Building," *Elect. Power & Energy Syst.*, pp. 355–358, 2015.

[19] H. Bs and R. Setiabudy, "Review of Microgrid Technology," *QiR (Quality In Research, International Conf.,2013:* IEEE Publication; pp. 127-132, 2013.

[20] M. Braun, "Optimization of microgrids short term operation based on an enhanced genetic algorithm." in *2013 IEEE PowerTech Eindhoven,201*3: IEEE Publication; pp. 20- 25, 2015.

[21] A. H. Chowdhury, "Optimum Economic Dispatch of Interconnected Microgrid with Energy Storage System," in *2015 International Conference on Electrical Engineering and Information Communication Technology (ICEEICT)*, 2015, pp. 21–23, 2015.

[22] G. G. Moshi, M. Pedico, C. Bovo, and A. Berizzi, "Optimal Generation Scheduling of Small Diesel Generators in a Microgrid," in *2014 IEEE International Energy Conference (ENERGYCON),* 2014, pp. 867–873, 2014.

[23] A. Karthikeyan, K Manikadan, and P. Somasundaram "Economic Dispatch of Microgrid with Smart Energy Storage Systems using Particle Swarm

Optimization," in *2016 International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC)*, 2016, pp. 783–789, 2016.

[24] F. Shariatzadeh, N. Kumar, and A. K. Srivastava, "Optimal Control Algorithms for Reconfiguration of Shipboard Microgrid Distribution System Using Intelligent Techniques," I*EEE Transactions on Industry Applications*, vol. 53, no. 1, pp. 474–482, 2017.

[25] S. Vasanthakumar, N. Kumarappan, R. Arulraj, and T. Vigneysh, "Cuckoo Search Algorithm based Environmental Economic Dispatch of Microgrid System with Distributed Generation," in *2015 International Conference on Smart Technologies and Management for Computing, Communication, Controls, Energy and Materials (ICSTM)*, 2015, pp. 575–580, 2015.

[26] M. D. Govardhan, "Artificial Bee Colony based Optimal Management of Microgrid," in *2012 11th International Conference on Environment and Electrical Engineering*, 2012, pp. 12–17, 2012.

[27] N. K. Paliwal, N. K. Singh, and A. K. Singh, "Optimal Power Flow in Grid connected Microgrid using Artificial Bee Colony Algorithm," in *2016 IEEE Region 10 Conference (TENCON)*, 2016, pp. 671–675, 2016.

[28] L. Ciabattoni, F. Ferracuti, G. Ippoliti, S. Longhi, and U. Politecnica, "Artificial bee colonies based optimal sizing of microgrid components : a profit maximization approach," in *2016 IEEE Congress on Evolutionary Computation (CEC)*, 2016, pp. 2036–2042, 2016.

[29] P. Li, S. Member, Z. Zhou, X. Lin, and X. Yang, "Dynamic Optimal Operation Scheduling of Microgrid using Binary Gravitational Search Algorithm," in *2014 International Conference on Power System Technology*, 2014, pp. 20–22, 2014.

[30] G. De Investigacion, D. Sistemas, and P. I. Indutect, "Study of a Renewable Energy Sources-Based Smart Grid. Requirements, Targets and Solutions," in *2016 3rd Conference on Power Engineering and Renewable Energy (ICPERE)*, 2016, pp. 45–50, 2016.

[31] L. Mariam, M. Basu, and M. F. Conlon, "A Review of Existing Microgrid Architectures," Hindawi Publication; vol. 13, pp. 1-8, 2013.

[32] R. Hamanaka and S. Obara, "Study on the fuel consumption in the Antarctica Showa Base microgrid," in *2016 IEEE PES Asia-Pacific Power and Energy*

Engineering Conference (APPEEC), 2016, pp. 1599–1603, 2016.

[33] Q. Zhai, "Application Potential of Solar PV , Wind and Fuel Cells Technologies for Global Sustainability Improvement," *ProQuest Dissertations Publishing*, pp. 53-96, 2012.

[34] M. H. Sulaiman, M. W. Mustafa, Z. N. Zakaria, O. Aliman, and S. R. Abdul Rahim, "Firefly algorithm technique for solving economic dispatch problem," *2012 IEEE Int. Power Eng. Optim. Conf. PEOCO 2012 - Conf. Proc.*, no. June, pp. 90–95, 2012.

[35] O. Abedinia, N. Amjady, and M. S. Naderi, "Multi-objective Environmental/Economic Dispatch using firefly technique," *2012 11th Int. Conf. Environ. Electr. Eng. EEEIC 2012 - Conf. Proc.*, pp. 461–466, 2012.

[36] A. Rastgou and J. Moshtagh, "Application of firefly algorithm for multi-stage transmission expansion planning with adequacy-security considerations in deregulated environments," *Appl. Soft Comput. J.*, vol. 41, pp. 373–389, 2016.

[37] P. Balachennaiah, M. Suryakalavathi, and P. Nagendra, "Engineering Science and Technology, an International Journal Optimizing real power loss and voltage stability limit of a large transmission network using firefly algorithm," *Eng. Sci. Technol. an Int. J.*, vol. 19, no. 2, pp. 800–810, 2016.

[38] M. G. Sundari, M. Rajaram, and S. Balaraman, "Application of improved firefly algorithm for programmed PWM in multilevel inverter with adjustable DC sources," *Appl. Soft Comput. J.*, vol. 41, pp. 169–179, 2016.

[39] G.-G. Wang, L. Guo, H. Duan, and H. Wang, "A New Improved Firefly Algorithm for Global Numerical Optimization," *J. Comput. Theor. Nanosci.*, vol. 11, no. 2, pp. 477–485, 2014.

[40] A. Hackl, C. Magele, and W. Renhart, "Extended Firefly Algorithm for Multimodal Optimization," in *2016 19th International Symposium on Electrical Apparatus and Technologies (SIELA*), 2016, vol. 1, pp. 21-43, 2016.

[41] M. Tuba and N. Bacanin, "Upgraded Firefly Algorithm for Portfolio Optimization Problem," *2014 UKSim-AMSS 16th Int. Conf. Comput. Model. Simul.*, vol. 1, no. 3, pp. 113–118, 2014.

[42] H. Wang, W. Wang, X. Zhou, H. Sun, J. Zhao, and X. Yu, "Firefly algorithm with neighborhood attraction," *Journal of Information Sciences*, vol. 383, pp. 374–387, 2017.

[43] S. M. Farahani, A. A. Abshouri, B. Nasiri, and M. R. Meybodi, "Some hybrid

models to improve firefly algorithm performance," *Int. J. Artif. Intell.*, vol. 8, no. 12 S, pp. 97–117, 2012.

[44] X. Wang and N. Zhou, "Pattern Search Firefly Algorithm for Solving Systems of Nonlinear Equations," *2014 Seventh Int. Symp. Comput. Intell. Des.*, pp. 228–231, 2014.

[45] X. Yang, "Firefly Algorithm, L´evy Flights and Global Optimization," Springer, pp. 200-218, 2010.

[46] M. Basu and A. Chowdhury, "Cuckoo search algorithm for economic dispatch," *Energy*, vol. 60, pp. 99–108, 2013.

[47] M. Younes, F. Khodja, and R. L. Kherfane, "Multi-objective economic emission dispatch solution using hybrid FFA (firefly algorithm) and considering wind power penetration," *Energy*, vol. 67, pp. 595–606, 2014.